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Advances of Nanofertilizers in Modern Agriculture; A review

S. Ilmudeen [a], F. Farween [a], S. Mahaletchumi [b], D. K. D. I. Kanchana [b,] *

[a] Faculty of Technology, University of Colombo, Sri Lanka
[b] Faculty of Technology, University of Sri Jayewardenepura, Sri Lanka
*dushanikanch@gmail.com

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Abstract: The key to agricultural sustainability is to carry out all farming activities in a sustainable manner. It is required for environmental assets such as animal varieties, greenery cover, soil, water, and energy sources such as solar, wave, and geothermal, are all to be conserved and enhanced. The essentials for the healthy, long-term operation of the economy are energy sources, climate, and ecological services agriculture. Furthermore, the widespread uses of herbicides, synthetic dressings on lands, and polluted water for irrigation have impacted agriculture. However, ensuring the food security of the growing population is a need. To address these difficulties, more creative solutions are required right away. In this sense, nanotechnology has aided the agro-technological revolution, which has the potential to change the robust agricultural system while ensuring food security shortly. Advanced nanotechnology is being used to increase sustainable crop yield while reducing the negative environmental effects of chemical fertilization. Nanotechnology improves agricultural production by boosting input efficiency while lowering losses due to the nanoparticles' larger specific surface area. The agrochemicals are carried by nanoparticles for increased crop protection through controlled distribution. The current paper provides an overview of recent advances in nanotechnology-based nanofertilizers, which have changed the agriculture industry. Furthermore, future perspectives on nanomaterial use in agriculture, their deliverables, limitations, and impacts of nano-agricultural threats are highlighted. As a result, this review states the recent initiatives and formulations of smart fertilizers, as well as the use of nanofertilizers in agriculture, which may aid in the development of solutions to existing and future chemical fertilization issues while achieving agricultural sustainability.

Index Terms:modern agriculture, nanofertilizer, sustainability, food security

1 INTRODUCTION

The agricultural sphere is claimed by the loss of global food security, climatic change events, depletion of fossil resources, groundwater contamination, soil erosion, less crop output, fruitless cultivation, and all of which are linked to the consequences of traditional agricultural applications. Although existing agrochemicals improve the crop output and suppress pests and diseases, they have a higher risk of causing negative long-term consequences [1]. Over the last six decades, chemical fertilizers have impacted rising agricultural output and have ensured the requisite provision of food around the world critically. Also, many issues have been observed with chemical fertilizers, including groundwater contamination, soil acidification, salinization, soil fertility degradation, the privation of biodiversity, and excessive energy consumption in synthesis processes [2].

However, the inability to meet rising food demand without relying heavily on chemical fertilizers is one of the hardest obstacles to overcome in achieving agricultural sustainability [3]. Technological advancements are seen as promising possibilities for transforming traditional agriculture into contemporary agriculture that is sustainable. Among various technologies, nanotechnology is a fast-evolving technology that has an impact on every part of the food system, including agriculture, food production, processing, packaging, transportation, shelf life, and nutrient bioavailability. One of the fastest-growing sectors in nanotechnology research is its application in the agri-food sector [4]. Nanofertilizers are one of the most essential tools in modern agriculture and agro-food, as well as a future economic driver. One of the key roles of nanotechnology in agriculture and soil sciences is the use of nanofertilizers in plant nutrition. The term "nanofertilizer" refers to a structure that supplies macro/micronutrients to plants in the range of 1-100 nm in size. Furthermore, this word should be expanded to include bulk materials used in conjunction with nanoscale structures to create novel products [5]. The incredibly small size of these materials, allows them to pass through barriers that are biological and permeate into the tissues of plants via root or foliar treatment, allowing for novel structured routes of nutrition and pesticide carriage. Furthermore, nanomaterial surface engineering can be used to create desirable features and functionalities.

2 ROLE OF FERTILIZERS IN CROP GROWTH

Plant nutrients are essential for long-term agriculture [6]. It is one of the most significant aspects of determining agricultural production and quality [7], and a balanced supply of key nutrients promotes crop growth [8]. Plant growth can be inhibited or stunted if one nutrient is deficient. As a result, fertilizers must be sprayed at the proper rate for ideal crop growth, taking into account crop requirements as well as agro-climatic surroundings [9]. That is because the soil itself lacks sufficient nutrient amounts and therefore, to achieve maximum growth, key nutrients (K, P, N) should be supplied externally to the plants [10,11]. Nitrogen, as a result, increases leaf growth and the formation of chlorophyll and proteins. Phosphorus promotes roots, flowers, and fruits growth [1]. It also has a strong positive correlation with plant growth and nitrogen uptake. As a result, it is often assumed that higher growth necessitates more N and P, with the implication that commonly coactive actions lead to greater development and absorption of both elements [8]. Potassium is necessary for stem and root growth as well as protein production [1]. Plants require micronutrients in addition to macronutrients for growth. In- plant defense systems, Mn, Zn, and Cu are essential micronutrients for enzyme activation and biomolecule synthesis [12]. As a result, enhancing nutrient efficiency is a suitable objective for all those who are related to agricultural and fertilizer manufacturing, with the support of scientists and agronomists, as well as farmers working towards that purpose. However, effectiveness cannot be surrendered for the sake of efficiency [13].

3 BARRIERS TO EXTENSIVE USE OF FERTILIZERS IN TRADITIONAL AGRICULTURE

Agricultural systems that include the use of synthetic chemical fertilizers, fungicides, herbicides, and other continuous inserts, or monoculture cultivation are referred to as conventional farming [14]. Criteria mentioned above state that traditional agriculture utilizes a lot of fertilizer to achieve the desired production. However, increased fertilizer usage does not make sure an increased crop output [15]. Although this type of agricultural production is sufficient to supply the present food request, there is various evidence that the substructure of their products is in danger [16]. The enormous disproportion between supply and removal of plant nutrients imposes a financial burden on the community, and the farmer, as well as a significant negative impact on nature [17]. For example, essential macronutrient components added to the soil, such as K, P, and N are lost by 50–90%, 80–90%, and 40–70% accordingly, resulting in a major deprivation of resources [18]. Only 50% of nitrogen, 57 % of phosphorus, and 64 % of potassium are contained in the consumable components of the animal body, according to the link between animal production and genuine consumption of animal commodities. The other half is pointless [17]. The aforementioned facts suggest that nutrient consumption efficiency is limited due to the large nutrient release rates of traditional fertilizers.

Inorganic fertilizers are produced artificially and designed in proper quantities and combinations to provide three primary nutrients: N, P, and K (nitrogen, phosphorous, and potassium) for a variety of crops and growing conditions [1]. Edaphic processes, on the other hand, lead to the immobilization of these elements in the soil, impeding their timely and sufficient uptake by plants [19]. According to experts, plants only utilize 30% of applied fertilizers, with the remainder being lost to leaching, mineralization, and bioconversion [8].

This will result in major environmental issues such as groundwater pollution and eutrophication of the water supply. Eutrophication is caused for an increased supply of nutrients to surface water, mainly nitrogen and phosphorus, resulting in increased production of key builders, particularly phytoplankton and aquatic plants [20]. Decreasing the standard of drinkable water, the emergence of foul smell, the generation of oxygen shortage in the extremity of water bodies, the production of hazardous NH_3, alterations in marine creatures' distribution, the growth and dwindling of fish stocks, and changes in the reproduction states of marine fish fauna, can all occur as a result of this [21]. Aside from that, nitrogen in nitrogenous fertilizers affects water resources, particularly groundwater, through draining, leaching, or flowing, posing a concern of groundwater pollution via 'nitrate,' the dissolved form of nitrogen [7,22]. Phosphate, nitrate, ammonium, and potassium salts are the most common ingredients in non-organic fertilizers [7]. The use of low-cost fertilizers and high-yielding crop varieties permits farmers to grow the same crop every year on the same field, a technique known as mono-cropping, without depleting soil nitrogen stores or incurring major pest issues. As a result, farmers started to focus their attempts on monoculture. Sadly, because of the soil salinity, these methods set the stage for substantial soil erosion [23], and the application of fertilizers regularly causes a decline in soil fertility, setting the door for more crop dropping in the future [18]. Furthermore, the fertilizer business is a source of natural radionuclides, (238U, 232Th, and 210Po) as well as heavy metals (Cu, Hg, Pb, Cd, Cu, and Ni) [7]. As a result, fertilizer application that exceeds the land requirement might result in a hazardous environment and agglomeration of heavy metals in soil and plant systems [24].

Other disadvantages associated with inorganic fertilizers include low bioavailability of nutrients due to nutrient alteration, termination of enzyme activation involved in plant defense, the need for fertilizers in huge amounts, the decline of crop standards due to unequal fertilizer usage, and cost increases for growers due to overuse of fertilizers. Therefore, integrated nutrient management systems (INMS), which include bio, chemical, and organic fertilizers, are becoming more popular. However, the downsides of this system, such as farmers' lack of understanding of this technique, demonstrate the need for another fertilizing approach that is more helpful than INMS. However, with these environmental and health costs, the long-term profitability of conventional agriculture appears to be in doubt [25]. As a result, the need to focus on new fertilizer technology was apparent, intending to develop an efficient, ecologically friendly fertilizing approach that would also be profitable in the long run.

4 SIGNIFICANCE OF NANOFERTILIZERS IN MODERN AGRICULTURE

Nanofertilizers are synthetic or altered versions of traditional fertilizers, complex fertilizers, or extracts from numerous vegetative or reproductive portions of the plant using various biological, chemical, physical, and mechanical methods to increase the agricultural production quality [13].

Because of the very small particle size, which ranges from 1-100 nm, nanofertilizers have a large surface area [13]. This facilitates higher nutrient use efficiency. The tiny surface area of Nanofertilizer gives more locations for many metabolic reactions in the plant organization. Furthermore, having a particle size smaller than the inlet size of leaves and roots allows for greater nutrient piercing into the plant from exterior parts such as roots or leaves [13]. Researchers state that citric acid surface-modified nanofertilizers that are produced using a wet chemical precipitation process can exhibit improved plant accessibility and solubility. Citric acid-modified hydroxyapatite nanoparticles, a phosphorus nanofertilizer is better than its natural form of rock phosphate [15]. Due to its high water solubility, it also reduces the less nutrient availability attribute of conventional phosphorous fertilizers [10]. Nanomaterials are often thought to play a role in the slow release of fertilizers. Furthermore, surface coatings or nano-coatings on fertilizer particles make them stronger than normal surfaces due to increased surface tension [26]. Nutrients can be encased in nanomaterials, covered with a fine preventive coating, or given as emulsions or nanoparticles in nanofertilizers [26]. In reaction to environmental changes such as wetness, soil acidity, and temperature this type of nanofertilizer can release nutrients more effectively than standard fertilizers [25]. In addition to these advantages, the regulated release method increases product quality by balancing plant nutrient supplies. It also helps plants deal with biotic and abiotic challenges in an indirect way. The urea-modified hydroxyapatite (HA) nanoparticles can be used as an excellent exemplar of a slow-release nanofertilizer. The use of nano-urea as a nitrogen supplier might overcome the problem of early degradation of urea in soil. [27-32].

Aside from that, HA–urea nanohybrids have been shown to have a significant favorable effect under adverse environmental conditions [33]. Despite this, a new urea & silica nanohybrid fertilizer [34] was produced to have a gradual and persistent urea release behavior for more than 10 days. The greener synthesis technique is used to produce this nanohybrid fertilizer and the surfaces of the silica nanoparticles are modified with urea. Consequently, for the successful and accurate transportation of silica and nitrogen, the application of urea-silica nanohybrids can be employed as control-release plant nutrition methods. Silica nano-particles serve a twofold purpose here, acting as both a conveyor matrix for urea and a source of silicon, a micronutrient required for vegetation growth [35]. Furthermore, when compared to pure urea, calcium carbonate nanohybrid particles modified with urea can be recognized as a new readily available, low-cost, and effective nitrogen fertilizer that slows nitrogen solubility by at least five times [36]. The application technique in the field is determined by the type of vegetation [13]. For nanofertilizers, different fertilizer application methods are available, such as soil and foliar application, and the soggy technique.

Apart from these benefits, nanofertilizers can be synthesized using a variety of materials, including TiO_2, Cu, Si, Al, C, Zn, and N, and have physicochemical features like structure, electrical charge, aggregation, and surface chemistry [23]. Due to the numerous advantages of nanofertilizers over conventional fertilizers that are currently available, as well as their high potential for achieving the goals of sustainable agriculture, ongoing research programs in nanotechnology-enabled fertilization should be evaluated for future explorations. In addition to fully comprehend the toxicity of nanomaterials and their consequences on the natural environment, more research is required [37] and ongoing scientific studies are required to fill in knowledge gaps and protective principles should be applied wisely. These activities should have a beneficial purpose of protecting the environment and human health while also preserving the everlasting viability of the nanotechnological industry [38].

5. FORMULATIONS AND ADVANCE TECHNIQUES OF NANOFERTILIZERS

5.1 Nanofertilizers and their formulations

Different fertilizer inputs have been downsized into smaller portions using mechanical or chemical processes, which may boost nutrient uptake and lower nutrient toxicity while reducing losses. Nanofertilizers can be produced from ammonia, urea, bio-fertilizers, other synthetic fertilizers, and some plant wastes. One of the formulation processes that urea settling on calcium cyanamide has resulted in fertilizer with nano-sized particles [39]. Also, blended urea was mixed with different bio-fertilizers to synthesize an effective nanofertilizer to obtain a slow nutrient supply for a prolonged time [40]. Some synthetic materials, peat, and ammonium humate can also be combined to create fertilizers in the nano range. To make such nanofertilizers, a mechanical/biochemical strategy is being applied, in which materials are mechanically ground into nano-sized particles and then biochemical processes are used to make efficient nanoscale formulations. Additionally, emulsions are combined with nano-colloids to obtain nano ranged emulsions [41]. In summary, fertilizers encapsulated in nanoparticles offer a broad range of possibilities for generating plant nutrient routines with increased nutrient uptake and utilization.

There are three distinct approaches to using nanoparticles to supply plant nutrients;

1. Encapsulating Plant nutrients in a variety of nanomaterials.
2. Applying a thin layer of nanomaterials, such as polymer film to nutrient particles.
3. Supplying nutrients in the form of nano-emulsions [41].

5.2 Slow and Control Release technique of Nanofertilizers

Controlled-release techniques based on nanoscale carriers prevent temporal overdosing and limit the number of agricultural chemicals utilized, lowering input and waste. One of the potential uses for nanotechnology in agricultural research is the slow and controlled release of fertilizers, bio-fertilizers, and micro-nutrients for high efficiency [42, 43]. The regulated release of nanocomposite fertilizers can increase the soil quality, facilitate crop utilization, balance the microorganisms, and boost crop production and development. Research by sandy loam soil-cultivated cucumber seedlings revealed that 0.5 g/kg of TiO_2 nanoparticles exposure brings out roughly 34% more Phosphorus inclusion and 35% additional potassium inclusion than those in the conventional method. Furthermore, nanocomposite fertilizers aided the colonization of the root surface by inducing secondary metabolite production, promoting plant development, and inducing secondary metabolite production in rhizosphere bacteria. By changing the demanded release, controlled-release fertilizers, such as penetrable NMs, considerably increase the absorption process in crops. When compared to traditional fertilizers, the application of slow-release fertilizers enhanced wheat output and soil surplus minerals, while also reducing nitrogen discharging by 25%.

5.3 Nutrients use efficiency (NUE) on plant

Nutrient use efficiency is the capability of crops to absorb and use nutritives for optimal yields and utilize nutrients for maximum output. The larger surface area of nanofertilizers is related to the smaller particle size, which provides extra platforms to promote different chemical and metabolic actions in the plants, resulting in more photosynthates. They have a lot of interaction with other compounds owing to their high surface area and small size. Nanofertilizers have particles that are fewer than 100 nanometers in size, allowing for greater permeability of nanoparticles into plants from the exterior such as soil or leaves [44]. The transit and storage of nutrients released from nanofertilizers in plants are affected by the size and the composition of nanofertilizers, diameter of the pores of cell walls, and plant physiology [45]. Nanofertilizers, based on zeolite have the potential to slowly feed nutrients to agricultural plants, improving nutrient availability during the cultivation period and minimizing nutrient loss owing to volatilization, nitrification, fixation, and discharging in the soil, particularly NO_3-N and NH_4-N. Nanoparticles, particles which sizes fewer than 100 nanometers can be utilized as fertilizer, allowing for more effective nutrient management while also lowering pollution. The fundamental reason for the great interest in fertilizers is that they have a higher penetration capability, a larger size, and a much larger surface area than the same bulk material. This owes in part to the high surface-to-volume ratio of nanoparticles. As a result, when compared to bigger particles, nanoparticles have a correspondingly higher reactive surface area. A particle's surface free energy is proportional to its size, and particle surface area grows as particle size decreases. Similar results were obtained in nanofertilizers, which provide more surface area and nutrient availability to crop plants, assisting in the improvement of several plants' quality parameters such as sugar content, protein, and oil content by increasing the rate of reaction or rate of synthesis processes in the plant system [44]. Furthermore, nanofertilizers' gradual and tailored nutrient release reduces plant toxicity and reduces N losses through leaching, volatilization, denitrification, and salt accumulation in soil [45].

Plant leaves also feature stomatal holes and nanopores that allow nanomaterial to easily enter and penetrate deep inside the leaves, allowing for better nutrient utilization (NUE). Plasmodium plasmodesmata are nanosized (50–60 nm) channels that promote cell-to-cell transfer within a plant. Because of their small size, nanoscale fertilizers effectively carry and release nutrients to multiple transport routes and plant surfaces via plasmodesmata. As a result, nanofertilizers improve field plant productivity (6–17%) and nutritional quality (lower nutrient losses) by increasing NUE and reducing nutrient losses [46].

6 DIFFERENT TYPES OF MODIFIED NANOFERTILIZERS

There are various varieties of nanofertilizers, each of which, due to its unique features, plays a vital role in delivering an agricultural revolution.

6.1 Macro Nutrient Nanofertilizers

Nanocomposites comprising macronutrients such as P, K, N; mannose, and amino acids are widely employed because they improve grain crop nutrient uptake and utilization. [47] Macronutrients, which comprise N, P, K, Ca, S, Mg, and others, are required in high concentrations. Macronutrients are ingested in bigger amounts and can be found in plant tissue in amounts ranging from 0.2 % to 4.0 % by dehydrated weight. While macronutrients (e.g. N, P, K) can be applied by combining inert nano-platforms like zeolite, hydroxyapatite, nano-clay, or chitosan nanoparticles with conventional fertilizers like ammonium, urea, potassium chloride, and calcium phosphate to act as a nutrition supply. The most common nitrogen source is urea, which has a particle size of more than 100 nanometers. Because of their big size, they are lost in the soil through leaching, ammonia emissions, and nitrogen oxides. For example, urea-modified hydroxylapatite (Ca_{10} $(PO_4)_6(OH)_2$) nanoparticles are a high-valued N-based nanofertilizer that provide phosphorus nutrition as well. Materials such as urea-modified hydroxyapatite and nano-enabled urea-coated zeolite chips have been employed to provide a regulated or gradual release of macronutrients like nitrogen [48].

6.2 Micro Nutrient Nanofertilizers

Micronutrients are important that plants require in extremely small amounts (less than 100 ppm) orchestrating their numerous metabolic processes. Chloride (Cl), iron (Fe), boron (B), manganese (Mn), molybdenum (Mo), copper (Cu), nickel (Ni), and zinc (Zn), are essential trace elements that are applied to plants. Micronutrients are consumed in small amounts, ranging from 5 to 200 parts per million (ppm), or less than 0.2 percent dry weight. Zinc is a very important and vital micronutrient that crops require in modest amounts. There is a lot of information about ZnO nanoparticles and how they might help plants growth and develop [49]. For example, in comparison to treatment with bulk $MnSO_4$, exposure of Vigna radiate (mung bean) to modified nano Mn fertilizers has enhanced the length of shoot and roots, biomass and rootlet number. In comparison to the control treatments, exposure to weathered and fresh ZnO nanoparticles in the soil dramatically boosted wheat shoot height and grain yield [48].

6.3 Chitosan Based Nano Materials as Nanofertilizer

Chitosan is a low-cost, biodegradable cationic biopolymer that occurs in nature. Chitosan's growth-promoting, antibacterial, and agrochemical delivery possibilities in herbs are now being investigated in depth. Chitosan is popular in agriculture due to its antibacterial characteristics, even in its bulk form. However, because of its insolubility in aqueous settings, bulk chitosan's efficacy in biological systems is limited [48]. A controlled release urea delivery method based on the interaction of humic compounds and urea put into chitosan nanoparticles Ionic gelation with chitosan was used to make NPK nanofertilizers. Furthermore, another technique for fertilizer delivery is the use of hydrogels films. Hydrogels have demonstrated the potential to gradually discharge their material load in the environment by absorbing water. By hydrogenating chitosan with salicylaldehyde, a controlled-release mechanism for urea has been developed. The goal of the research was to improve soil fertilization and water retention [51]. To improve the transmitting efficiency of the plasmid DNA (pDNA)–SWNTs combination into the chloroplasts, chitosan-functionalized single-walled nanotubes (SWNTs) were created utilizing the lipid exchange envelope penetration model [52] Antimicrobial coating surfaces and anti-oxidants for reactive oxygen species (ROS) suppression have all been extensively investigated in plants using chitosan-based nanomaterials. Chitosan exhibits a strong affinity for metals [53]. The herbicide clopyralid was adsorbed and disposed of using a nanocomposite material made of chitosan and montmorillonite.

6.4 Nano Bio-Fertilizer

Plant materials are used in the biosynthesis of nanoparticles such as CuO nanoparticles and ZnO nanoparticles, which are bio-nanofertilizers. Moringa, banana peels, Rhamnus virgata, and onion are just a few of the plant extracts that have been used to make nanofertilizers. Some microorganisms (bacteria, fungus, and actinomycetes) and plant extracts could be used to manufacture nanofertilizers [54]. Biofertilizers are predominantly composed of live microbe compositions like fungal mycorrhizae, blue green algae (BGA), rhizobium, azotobacter, and some bacteria such as *Bacillus sp.* and *Pseudomonas sp.* They have the ability to breakdown complicated organic particles into manageable simple parts. The use of this approach in garbage disposal is gaining traction around the world, transforming biodegradable trash into organic fertilizers/compost thus decreasing carbon losses and soil erosion.

7 LIMITATIONS AND IMPACT OF NANOFERTILIZER IN THE FRAMEWORK OF SUSTAINABLE AGRICULTURE

Nanofertilizers have proven to be effective in increasing crop yields in recent years, thanks to technological advancements. On the other hand, the deliberate deployment of this technology in agricultural activities could result in a slew of unintended and irreversible consequences. New health and environmental safety concerns may restrict the applying new technologies in the manufacturing of horticulture crops in this situation [56]. Different nanoparticles influence plant growth in different ways. By connecting to carrier proteins, aquaporin, iron channels, endocytosis, forming new pores, or binding to organic chemicals in the surrounding medium, nanomaterials can enter the plant. Nanoparticle penetration into seeds is likely to be challenging compared to plant cell walls and membranes due to the substantially thick seed coat covering the entire seed. Treatment of soybeans (Glycine max) with a low-concentration mixture of nanoscale SiO_2 and TiO_2 increased germination and plant growth. N_2 fixing by nano anatase TiO_2 was linked to improved spinach growth in N-deficient conditions. When exposed to sunshine, nano anatase TiO_2 could chemisorb N_2 directly or decrease N_2 to NH_3 in spinach leaves, converting it to organic nitrogen and enhancing spinach growth. Natural nanoparticles are abundant in the soil as a result of constant weathering and re-arrangement of its geogenic ingredients, as well as significant biological activity. Because of their highly reactive nature, extensive and unregulated use of engineered nanoparticles may result in their buildup in the environment, agricultural areas, and waste bodies, changing the physiochemical and biological aspects of soil. As a consequence, it's essential to investigate the impacts of discharged nanomaterial on soil microorganisms [57] exposed to nanofertilizer manufacture as well as field application of nanofertilizers. The practicality and usefulness of these revolutionary smart fertilizers must be investigated. Indeed, toxicity, transportation, and bioavailability limitations, and unforeseen natural repercussions from contact with biological systems, limit their usage in horticulture and sustainable agriculture. Nanoparticle intake, transformation, translocation, and accumulation (phytotoxicity) in plants are all regulated by several factors such as dose, application method, species and the type of nanoparticles used. Therefore, it is necessary to examine the degree of poisonous of each nanoparticle in any given crop in order to investigate the uptake and translocation of nanofertilizers and the behavior of nanofertilizer in the plant and soil environment [56].

8 FUTURE PERSPECTIVES OF NANOFERTILIZERS

Despite the benefits of nanomaterials and nanotechnology, using such a new-emerging technology has posed several challenges that must be overcome to turn these faults into positive opportunities. Environmental advocacy groups continue to raise awareness about the dangers of nanomaterials and nanoparticles. They do not, however, have sufficient awareness about the dangers and safety of nanomaterials. Simultaneously, regulatory agencies around the world expanded their definition of "nano" in the food and feed chain, requiring individual component testing for every nano-based composition to ensure its safety. Due to their incompatibility with present market restrictions, these limits have hampered the approval of current pending nano products, as well as the willingness of major companies in the agri-food industry to spend more on revolutionary nano-based formulations [58] Moreover, nanotechnology has received very little attention in the agricultural industry, because the majority of nanomaterials are metallic and may cause soil metal contamination, selecting the application strategies, appropriate nanomaterial types and dosages are crucial for obtaining advantageous results.

For global food security projects, the invention and deployment of suitable new nanofertilizers can come up with possible techniques to enhance plant growth and development as well as production [59]. Nanoparticles provide magnificent paths for a wide variety of biological approaches. It encourages more researchers to pursue future discoveries in the fields of medicine, healthcare, bio and electrochemical sensors, and agriculture [60]. Using the environmentally friendly protocol in this way could be beneficial. Toxicity is comparatively small or non-existent and future the focus of research should be on their functioning aspects. Furthermore, pilot trials must be conducted in a natural setting. Circumstances (soil-grown plants) to provide an explicit impact of nanoparticles on the environment are depicted. The new study intends to improve plant efficiency in terms of water, herbicides, and fertilizers, as well as reduce pollution and make agriculture safer and environmentally friendly. Nanotechnology has the potential to supply and fundamentally streamline present environmental detection, monitoring, and cleanup technologies.

During the next two decades, nanotechnology will help to accelerate the green revolution and will change agriculture, particularly pest management. Novel insecticides, pesticides, and repellents can all benefit from nanoparticles. For a variety of reasons, including public opposition to genetically modified (GM) crops, a lack of research, development, and technological units in the government agricultural sector for nano-type explorations, and inadequately knowledge and technologies, the future of nanoscience in agriculture is uncertain. There is a strong call to cut down the jagged shape that exists between society, the average person, and growing scientific notions, and if we succeed, an unexpectedly bright and helpful future will be waiting for society [60].

9 CONCLUSION

Nanofertilizers are gaining popularity as a viable approach to meet the world's expanding food demand, as they reduce some of the key issues associated with conventional fertilizers, such as plant bioavailability, toxicity induced by fertilizer overuse, and low nutrient utilization efficiency. Nanotechnological approaches including magnetized fertilization, controlled release, surface functionalization, controlled loss, nutrient encapsulation, and the use of nano-coatings or nanocomposites are mostly responsible in this field. The smartest techniques for modern agriculture are nano-sized delivery devices and continuous release. In addition, cost-effective analysis of the usage of ENMs must be done in all circumstances. Given the low-profit margins involved with agriculture/food production, new tactics must be as effective as traditional approaches in terms of both cost and efficacy. Ultimately, researchers and regulators should be held accountable for the danger and limitations of nanofertilizer use to maximize the benefits of nanofertilizers for sustainable crop production in a changing climate while minimizing the risk of contamination. nanofertilizers have the potential to boost agricultural output as well as resilience to biotic and abiotic stressors. As a result, nanofertilizers serve a critical function in agriculture that cannot be overlooked. The use of nanofertilizers may help to reduce fertilizer use by delivering active components more efficiently boosting nutrient uptake and NUE values, and reducing fertilizer losses and energy consumption during production.

Future research should concentrate on the safety, bioavailability, and toxicity of various nanofertilizers or nanoparticles utilized in agriculture. To further boost yields in sustainable agriculture, bio-synthesized or green synthesized nanobiofertilizers and nanofertilizers should be investigated.

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